12 The Amonix High-Concentration Photovoltaic System

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12.1 Introduction

Amonix Incorporated (Torrance, Calif.) was established in 1989 to develop and commercialize a solar high-concentration photovoltaic (HCPV) system based upon a custom silicon cell developed by Amonix in collaboration with the Electrical Power Research Institute (Palo Alto, California). By optically concentrating large areas of sunlight onto small-area solar cells, HCPV systems provide a primary benefit of semiconductor material cost reduction. The HCPV systems, however, do require additional components to those needed by fixed flat-plate PV systems. The additional components required are:

1. An efficient optical concentration system (lenses and/or mirrors)
2. A structural system that can support the solar cells and the optical components and maintain their respective orientations.
3. A tracking control and drive system that establishes and maintains, throughout the day, accurate optical alignment between the sun, optical components and solar cells.

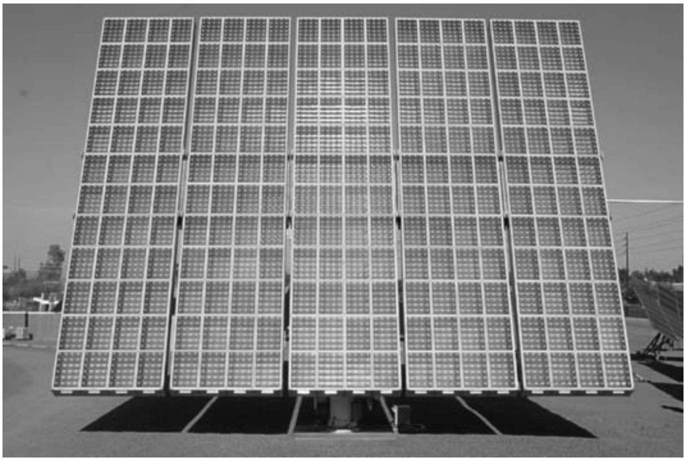

Fig. 12.1. An Amonix 25-kW unit in operation at the Arizona Public Service STAR facility in Phoenix, Arizona

Amonix has focused on utility-scale applications for solar electricity generation, such as the one shown in Fig. 12.1. This chapter describes the development, fabrication, installation and performance of the Amonix HCPV system.

12.2 Why Solar-Concentrating Photovoltaics?

Before photovoltaic systems can provide a substantial part of the world's need for electrical energy, there needs to be a large reduction in the cost. Studies conducted by the Department of Energy (DOE) [1], Electrical Power Research Institute (EPRI) [2], and others [3] concluded that concentrating solar energy systems can eventually achieve lower cost than conventional flat-plate PV power systems. The lower cost results from the following:

1. Lower material expense. The semiconductor material for solar cells is a major cost element of all photovoltaic systems; therefore, reducing the amount of required solar cell material is an effective approach to lowering PV system cost. Amonix has pursued this approach by using low-cost Fresnel lenses to focus large areas of sunlight onto small solar cells, which reduces the required cell area/material by over 500×. A 6-in. wafer used in a flat-plate PV system produces about 2.5 W, but it produces the equivalent of 1000 watts under concentrated sunlight in the Amonix system, as illustrated in Fig. 12.2.
2. Higher cell efficiency. Concentrating PV cells achieve higher efficiencies than do non-concentration PV cells. Flat-plate PV silicon cells have efficiencies in the range of 8 – 15%, whereas the Amonix concentrating silicon cell has an efficiency of over 27%. Multijunction concentrating cells are still in the developmental stage but have achieved efficiency greater than 37%.
3. Increased annual energy production. Increased annual energy production is achieved by the incorporation of two-axis sun tracking which is an inherent requirement in any concentrating system. All high-concentration systems require a sun-tracking control system. This improves the annual energy generated per installed kilowatt by reducing cosine losses,

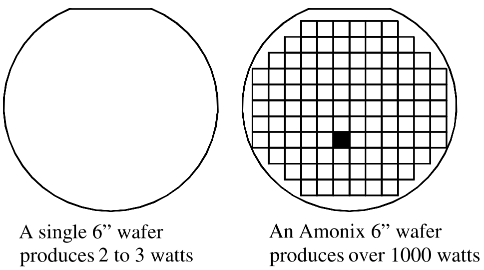

Fig. 12.2. Concentrating reduces the material cost per watt

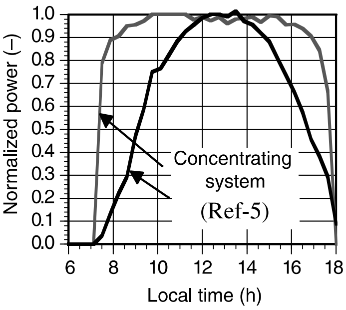

Fig. 12.3. Daily power produced

as shown in Fig. 12.3. Data on the annual energy generated by existing flat-plate PV systems illustrate this point: the average annual energy produced by 19 different fixed flat-plate installations in California ranged from 1000 kWh per rated kilowatt to 1500 kWh per rated kilowatt. As is shown later, the Amonix system generates in excess of 2000 – 2200 kWh per rated kilowatt in the Phoenix, Arizona, and Las Vegas, Nevada plants.

12.3 Solar Cell Development

The inherent very-high-efficiency point contact, rear-junction solar cells that are used in the Amonix system were first published by R.J. Schwartz and M.D. Lammert at Purdue University in the 1970s (Fig. 12.4). The structure proposed then is quite similar to that currently fabricated by Amonix. The high efficiency is derived from the combination of zero metal shadowing, efficient light trapping (textured top side and reflective bottom) and point-contact design for reduced recombination. The initial device design utilized

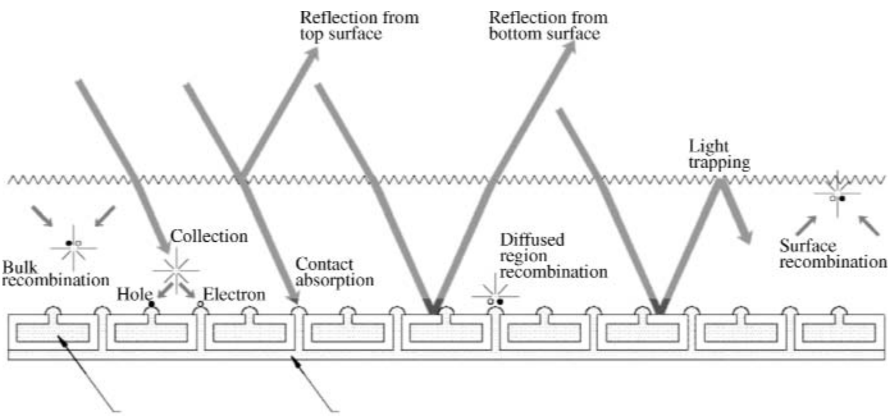

Fig. 12.4. Cross section of the Amonix point-contact, rear-junction solar cell

100-μm-thick silicon with the n and p (negative and positive) contacts on the rear of the cell, on a pitch of about 200 μm. Amonix still uses thin silicon (between 100 and 125 μm), although the pitch of the n and p regions has been reduced below 100 μm. A significant body of work was produced at Stanford University on the science of this device's operation, such as the effect of front-surface recombination velocity, Auger recombination and determination of the recombination due to heavily diffused regions. These contributions to semiconductor science were very applicable to the point-contact, rear-junction solar cell, as was evident by the device efficiency improvements that were achieved by the Stanford group. By the mid- to late 1980s, the foundation had been laid for the design of an efficient concentrator silicon solar cell, and the next challenge was to manufacture this cell; however, various design hurdles remained, such as how to overcome the solar cell's efficiency degradation when exposed to UV radiation. These design problems led EPRI (Electrical Power Research Institute), which was funding the solar cell's development, to contact MA/COM of Torrance, California. MA/COM, a company with experience in radiation protection of silicon microelectronic devices, was able to achieve UV stability in the concentrator solar cells. The effort then moved towards manufacturing. A company called Acrian was involved in this work, but they soon discontinued their efforts due to consistently low electronic yields. Although the concentrator cell design had achieved high sunlight-to-electricity conversion efficiency, the rigors of industry and manufacturability had not yet been effectively addressed.

In the 1990s, both Amonix and SunPower developed concentrator cell manufacturing processes with increased yield rates, although the cells were of lower efficiency than Stanford's demonstration cells. These acceptable-yield manufacturing methods produced enough cells for large-sample field installation and performance characterization. Many companies were initially involved in this, and field testing showed that the devices were indeed stable under various environments. The availability of concentrator solar cells also allowed various concentrator PV companies to test their sunlight concentrating/tracking systems using solar cells that were actually suitable for high-concentration sunlight. Amonix has almost single-handedly demonstrated long-term reliability of its point-focus, refractive-concentrator system. Solar System of Australia has carried out long-term field experience with its reflective-concentrator system – both companies using the silicon point-contact rear-junction concentrator cell to gain such experience.

SunPower, however, discontinued manufacturing their concentrator cell. This placed the system-based concentrator PV companies in a precarious position: From where would they obtain silicon concentrator cells, when Amonix was the only other company that can produce the cell, but Amonix was not selling the cell to anyone? The only alternative, viable or otherwise, was for system-based concentrator PV companies to start trial of the multijunction concentrator cells. Due to the now limited supply (outside of Amonix) of silicon concentrator cells, most of the research community has become devoted to the development of multijunction cell technology.

Although the research community has thus largely abandoned the silicon concentrator cell, the impact on Amonix has been negligible. The next stage of development for the silicon concentrator cell is of cost reduction and mass production – disciplines primarily conducted internally in a company and thus without the input of university researchers. What is Amonix's current status of cell development and production? In the early 2000s the semiconductor industry went from boom to bust, thus enabling Amonix to work more closely with semiconductor factories to develop a simplified, though robust, process for producing these cells in what was then newly-found capacity. The simplified process was first run in September 2002 and has been run various times since (without change) to produce the (approximately) 1 MW of concentrator cells that Amonix required for field testing its fifth-generation system. During this time Amonix also tested some production cells at Fraunhofer Institute in Germany and claimed the world record for silicon solar cell efficiency at 27.6% – almost double the efficiency of the standard silicon solar cells produced for flat panels. Since then, Amonix's cell size has been reduced by 40%, with sunlight concentration increased in proportion, further reducing cost.

Current challenges being undertaken are to manufacture the cell in consistently high volumes and to reduce the process cost through experience and process control stability. This work is being done in a low-tech manufacturing environment so that the overhead cost of production can be substantially reduced.

12.4 HCPV Development

Amonix knew that the development of the HCPV system would meet many challenges towards achieving market cost and performance requirements. The market cost goals would place demands on the manufacturing cost, the installation cost and the operating cost. In order to achieve these goals, the system designers gave consideration to:

1. System manufacturability. The system design (a) should minimize the amount of required material, (b) should not require precise structural tolerances, (c) should minimize the quantity of manufacturing steps and processes, and (d) should be automation-manufacturable, in order to reduce labour cost.
2. Transportation. Components must be transported to the factory, and completed systems must be transported to the installation site. The amount of transportation, and therefore transportation costs, should be minimized. Consideration must be given to the highway transportation limitations of different states.

3. Installation time and procedures. Due to the typically remote desert siting of many large-scale PV installations, and due to the associated vulnerability to weather conditions, consideration should be given to (a) minimizing site installation time, and (b) choice of appropriate installation equipment.
4. System reliability. Since the costs of field retrofits and field maintenance are very high, the system design should be intrinsically reliable. The system should incorporate remotely accessible, diagnostic information acquisition that can be used for monitoring system performance and for planning necessary maintenance.
5. Operation requirements. The system operation should be fully automatic, to eliminate the requirement for an operator.

The performance specifications should consider:

1. The performance life of the system, subsystems and components.
2. The environment that the system will encounter in the intended market region. Although the market region might be limited to the 'solar belt' around the world, the operating specification should include the temperature, wind, snow, humidity, etc., extremes of these regions.

In order to minimize commercial risk, Amonix's development plan included the fabrication and complete field testing of its prospective designs, as illustrated in Fig. 12.5. The lessons learned from this field testing, as well as from the manufacturing and installation processes, were incorporated back into the system design. The systems were installed at different sites in the southwest, including Texas, Georgia, California, Nevada and Arizona.

During its first few years of operation (1989–1992), Amonix was focused upon the development of a stable, high-concentration back-junction silicon cell, and upon establishing manufacturing capability with semiconductor foundries. In late 1991, the efficiency of the Amonix cell was measured at 26.5%. In 1992, once the solar cell's performance and stability were well on their way to being established, Amonix began investigating system designs for integration with its back-junction silicon cell. A Fresnel lens system was selected for sunlight concentration. An enclosed support structure was designed

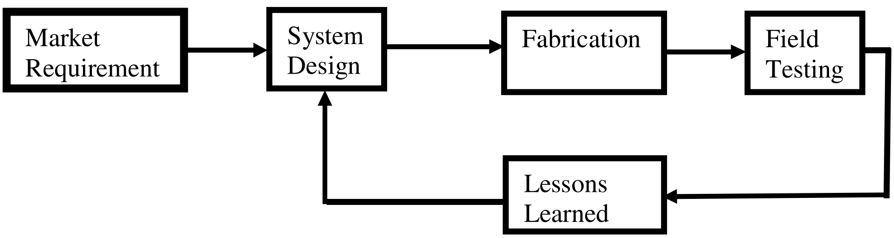

Fig. 12.5. The Amonix development plan depended upon lessons learned from field verification testing

to house, and to establish relative alignment between, the Fresnel lenses and solar cells. This support structure would be mounted onto a single pedestal equipped with elevation and azimuth drive systems.

The first prototype 20-kW system was deployed at Arizona Public Service (APS) Solar Test and Research (STAR) facility in Tempe, Arizona, in October 1994. A second prototype system was installed at the PVUSA facility in Davis, California, in September 1995 as part of the Emerging Technical Program (EMT-3). In late 1996, 20-kW systems were installed for both Nevada Power Company (NPC) and West Texas Utilities.

These prototype installations of the Amonix HCPV system were limited to single-site systems, primarily for demonstration and utility evaluations. In 1999 Amonix contracted with Arizona Public Service (APS) to install 300 kW of the HCPV system within APS's service area. This project represents the largest deployment of high-concentration PV in the world at this time.

In May 2000, three 20-kW systems were installed, and began producing power, at the APS STAR facility. Four 25-kW systems were installed at an APS site in Glendale, Arizona. Amonix's first 35-kW system was installed at the APS STAR facility in July 2001. Two more 25-kW systems were installed later that same year. Five more 25-kW systems were installed in 2002 at the APS STAR facility. Five 35-kW systems were installed at an APS site in Prescott, Arizona, starting from January 2003.

In late 2003, a project began to install an Amonix High Concentration Photovoltaic (HCPV) system at the Centre for Energy Research, located on the campus of University of Nevada, Las Vegas. This project is a joint effort by UNLV, Amonix and Arizona Public Service under the direction of the National Renewable Energy Laboratory (NREL) and funded by Nevada Southwest Energy Partnership. The primary purpose of the project is to generate a database on the performance and reliability of the system.

In 2006, three 25-kW systems were installed at the Clark Generating Station of the Nevada Power Company in Las Vegas.

12.5 Application

Amonix's HCPV system has been designed to serve a variety of power needs and applications. The HCPV system can be sized for generation capacities of 5, 10, 15, 20, 25 or 35 kW. Early in the development, 15- and 20-kW systems were fabricated and field tested. Since 2001, only 25- and 35-kW systems have been fabricated and field tested. Some of the designed applications of the HCPV system are:

1. Utility-scale, grid-connected power. Amonix's MegaModule Generating Systems can be combined to form multi-megawatt power farms that deliver power directly into a utility's electrical grid system. Such applications allow utilities to diversify their fuel mix and become less reliant upon

traditional coal- or natural gas-fired generators. Energy generated by the HCPV systems is clean and environmentally benign. The HCPV system can be used to reduce the utility's peaking load during the hot summer months. The modular design of a multi-megawatt HCPV system allows its generating capacity to be incrementally brought online, following the daily peak power curve. The modular design also allows decentralized siting of generating capacity, helping to relieve overloaded transmission lines and defray the high cost of installing new grid transmission lines. Unlike most conventional power stations, on which construction must be completed before power production can begin, an HCPV system will begin producing power when its first array is installed and field-wired. Figure 12.6 shows five 35-kW HCPV systems connected to Arizona Public Service Company's electrical grid.

2. Village/rural electrification. Amonix's HCPV system has been designed for automatic stand-alone operation and high reliability. Its daily sun-tracking is self-directed, requiring no external or operator input. It has also been designed such that, if a solar cell (or multiple cells) fails, the rest of the HCPV system will continue to produce power. The HCPV system can also operate in locations that have no access to the electrical grid, either due to their remote location or due to the economic constraints of the region. A very large part of the world population does not have access to electrical power. The HCPV system can be installed to provide power for these communities, as illustrated in Fig. 12.7. As their needs grow, additional systems can be installed. The HCPV can provide 24-h power by the addition of an electrical storage system.
3. Water pumping. Much of the developing world needs electrical power to pump water for home use and farming. The Amonix HCPV system's automatic operation and high reliability makes it ideally suited for this

Fig. 12.6. Five HCPV systems generating power for the APS grid

purpose (Fig. 12.8). Because the HCPV system tracks the sun, it will provide 30% more daily generated energy than fixed flat-plate photovoltaic systems.

Fig. 12.7. The Amonix HCPV system can supply power to remote villages

Fig. 12.8. The HCPV system can provide electrical power for water pumping

Fig. 12.9. The HCPV system can provide electrical power directly to desalinization plants

4. Industrial electrical power. Many industrial plants pay high per-kilowatt-hour electricity rates, because they use large quantities of utility-sourced electricity during the utility's daily peak-use period. An HCPV system, located at a plant facility, can reduce that plant's demand for expensive, peak-use period electricity. The HCPV system will also, of course, reduce the plant's total demand for utility-sourced power. The HCPV system can also supply electrical power for water desalinization and purification projects, as illustrated in Fig. 12.9.

12.6 System Description

The MegaModule system shown in Fig. 12.10 is composed of five major subsystems. The major subsystems of the HCPV system are:

1. MegaModule: structure that houses and supports the system's solar cells, concentrating optics and electrical connections. There can be from five to seven MegaModules in a system.
2. drive subsystem: allows the MegaModules to be rotated and positioned directly towards the sun. This subsystem is composed of a pedestal, drive head, hydraulic actuators and torque tube.
3. Tracking control electronics: determines the position of the sun, and controls the hydraulic actuators that position the MegaModules directly towards the sun. The tracking control also senses wind speed and directs the MegaModules to assume a wind-stow position in response to excessive wind speeds.
4. Hydraulic subsystem: activates and deactivates the hydraulic valves that serve the hydraulic actuators of the drive subsystem.
5. Power conditioning subsystem: converts the MegaModules' DC power into AC power, and interfaces the HCPV system with the grid.

Fig. 12.10. Major subsystems and components of the Amonix HCPV system

12.6.1 MegaModule

The Amonix HCPV system uses square Fresnel lenses, with circular facets, to concentrate the sun's irradiance onto the solar cells, as illustrated in Fig. 12.11. The angle of each lens facet varies as a function of that facet's distance from the centre of the lens, such that all the sun's rays will converge at the location of the small solar cell. The Amonix system uses Fresnel lens 'parquets', each consisting of a number of these square Fresnel lenses, rectangularly arrayed within a single sheet. The solar cells are mounted onto modular plates, arrayed and spaced to match the positions of the lens array. The lens parquets and solar cell plates are mounted to the MegaModule structure, as shown in Fig. 12.12.

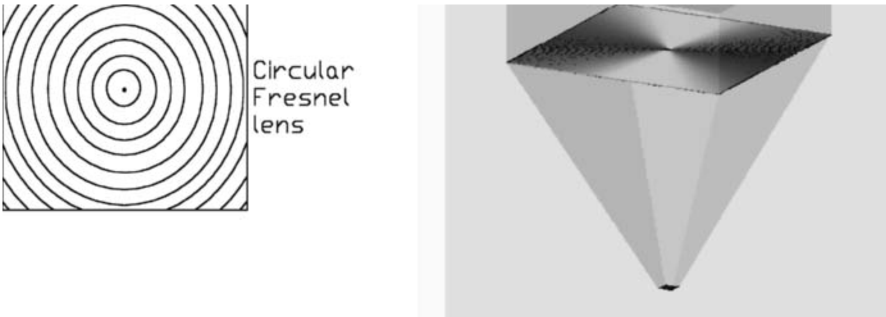

Fig. 12.11. Fresnel lens concentrates the sun's irradiance onto the solar cell

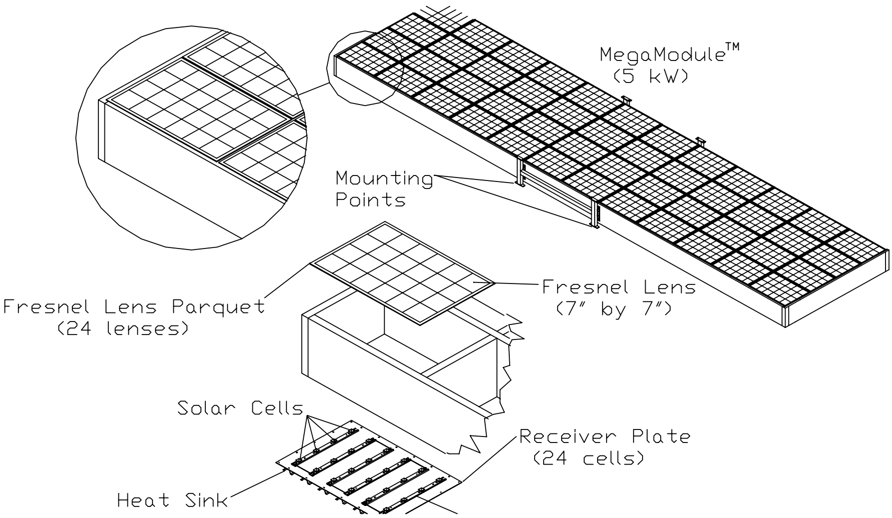

Fig. 12.12. A MegaModule is composed of lenses, solar cell receiver plates and the support structure

12.6.2 Drive Subsystem

The patented Amonix mechanical drive system incorporates three linear hydraulic actuators. One actuator is employed for elevation-axis movement, and two actuators are employed for azimuth-axis movement.

The elevation drive system can operate at two speeds: high speed (for quickly moving the MegaModules into their face-up, high-wind stow position); and low speed (for normal sun tracking movement). The system can move from any position into a face-up wind stow position in less than 15 s. It also has a fail-safe wind stow function: if there is an interruption of power to the control system, the elevation drive will automatically move the MegaModules into wind-stow position, using stored hydraulic pressure from an accumulator.

The two azimuth-drive actuators, by their coordinated extension or retraction, are capable of moving the MegaModules through a full 360° of azimuth rotation.

The drive system is designed to survive a 90-mph wind, and to track the sun up to an average wind speed of 29-mph.

12.6.3 Tracking Control Electronics

The Amonix IHCPV tracking control electronics uses open-loop control algorithms, with modifying inputs from a sun-position detector. Position encoders are linked directly to the elevation and azimuth final drive stages. The open-loop control algorithms calculate the sun's position based upon time-of-day and geographic location data obtained by the system's onboard GPS unit. Information on the MegaModules' current position is inputted to the control electronics by the position encoders. Based on these data, the control electronics calculates the drive movement increment necessary to bring the MegaModules into alignment with the sun. Input from the sun position detector allows the control electronics to quantify and make adjustments for any small tracking errors.

The electronic controller is completely autonomous but can be monitored and controlled remotely. At night, the control system positions the MegaModules in a face-up position. In the morning, when the sun rises to a selected minimum angle above the horizon, the controller moves the MegaModules to face the sun's position. When the sun's irradiance is sufficient for power production, the inverter will automatically establish connection to the grid and start producing power automatically. The controller maintains the array pointing at the sun over the day. In the event of heavy cloud cover, the inverter will automatically disconnect from the grid, but the system will continue to track the sun. When the cloud cover dissipates sufficiently, the inverter will reconnect to the grid and start producing power, within minutes. At the end of the day, when the sun's elevation angle falls below the selected minimum, the system will moved to its night stow position.

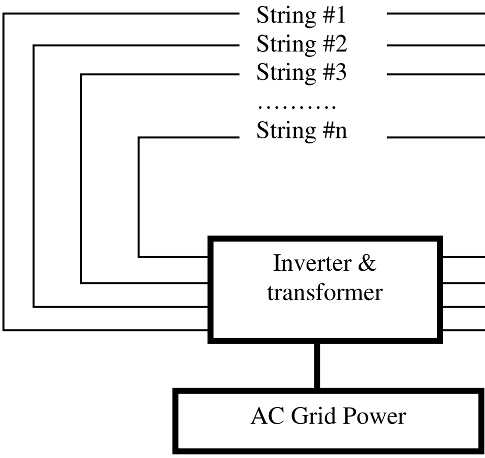

Fig. 12.13. Power output wiring configuration of the HCPV system

An anemometer is mounted onto each array. If the wind speed exceeds a selected maximum, the controller moves the array to a face-up stow position. It will stay in the wind stow position until the wind speed falls below, and stays below, a selected maximum for a pre-selected time period. The system then returns to tracking the sun and generating power.

The power output wiring configuration for the Amonix IHCPV system is shown in Fig. 12.13. Each MegaModule is divided into two power output wiring strings. Each string is composed of 576 series-connected solar cells. For the sake of reliability, the strings of each array are, in turn, wired together in parallel. If a problem occurs with an individual string, the power from that string may be lost, but the power generation of the other strings is not affected. For further reliability, each individual solar cell has a parallel-connected bypass diode, which prevents a bad cell from interrupting the power production of the rest of the string. If a solar cell does fail, only the power of that cell and the drop across the bypass diode are lost, approximately 10 W total. Collectively, these features greatly increase system reliability by reducing the number of single-point failures that could reduce power output to zero. Failures of the inverter, transformer or drive control system are the only major single-point failures that would take the array off-line. Other failures only result in reduced power production.

12.7 System Installation

The support pedestal of the HCPV system is mounted within a concrete-poured hole, which is drilled 3 ft. (ca. 1 m) in diameter and 18 ft. (ca. 5.5 m)

Fig. 12.14. A drilling rig drills the foundation hole

Fig. 12.15. Installing the pedestal

Fig. 12.16. Installation of the drive/ torque tube assembly

deep into the ground. A drilling rig (Fig. 12.14) suitable for the drilling operation is pictured left. The finished foundation hole is pictured right.

The pedestal is inserted in the foundation hole and concrete is poured around it. The completed pedestal installation is shown in Fig. 12.15. Next, the drive/torque tube structure is lifted and positioned onto the pedestal by means of a crane equipped with lifting straps, as shown in Fig. 12.16.

MegaModules are delivered to the site by truck, with up to three Mega-Modules per truckload. A crane is positioned as shown in Fig. 12.17, such

Fig. 12.17. A crane lifts the first module from the truck to the torque tube

Fig. 12.18. The final module is installed on the torque tube

that it can lift the MegaModules directly from the truck and onto the drive subsystem. The first module is installed in the centre position of the torque tube. The next two modules are mounted on either side of the centre module, and then the two outside modules are added to complete the module assembly, as shown in Fig. 12.18.

12.8 System Operation

The Amonix HCPV system is designed for unattended operation for either grid-connected or non-grid applications. When the sun reaches a given elevation angle in the morning, the system moves automatically from a night stow position to sun-tracking position. When the sun's insolation reaches a certain

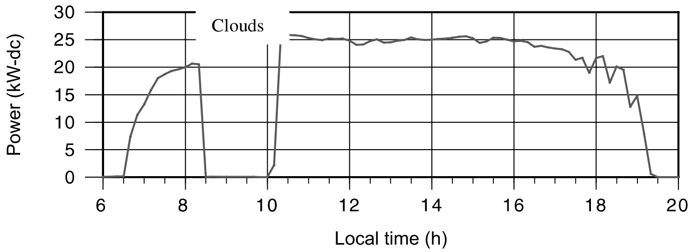

Fig. 12.19. Power output of an HCPV system, over the course of a day

level, the inverter will automatically connect to the grid and start outputting electrical power. It tracks the sun throughout the day, generating electrical power whenever the direct normal irradiance (DNI) is above 400 W/m^2, until the sun sets in the evening time.

An example of daily generated power output is shown in Fig. 12.19. On this particular day, in the late morning, a dense cloud occluded the sun and reduced power output to zero. Later, after the cloud passed, power output resumed and reached 26 kW. A thin cloud layer then decreased power output to 25 kW for most of the day, until late afternoon when small cloud clusters caused the power to fluctuate.

Throughout the day, the electronic control subsystem monitors the sun's position with respect to the MegaModule array's position, and adjusts the array's position if required to maintain the required pointing accuracy. If clouds occur during the day, such that the sun position sensor receives no input, then mathematical sun algorithms are used to maintain the array's alignment with the sun's calculated position, until the clouds dissipate.

12.9 Description of Plant Sites

Over 600 kW of the fifth-generation Amonix HCPV system have been manufactured and installed over the past 6 years. The first three 20-kW units started operating in May 2000. Since that time, additional units have been manufactured and installed for Arizona Public Service (APS), University of Nevada at Las Vegas (UNLV), and Nevada Power Company, Las Vegas. During this time, the units have produced over 3.8 GWh of grid energy.

12.9.1 APS STAR Center, West Field Site

There are currently 145 kW in operation in the West field at the APS STAR facility in Tempe, Arizona. The field now consists of three 25-kW units and two 35-kW units. Initially, there were three 20-kW units and three 25-kW units as shown in Fig. 12.20. The MegaModules from the three 20-kW units were moved to a new 35-kW drive system. These units were installed during

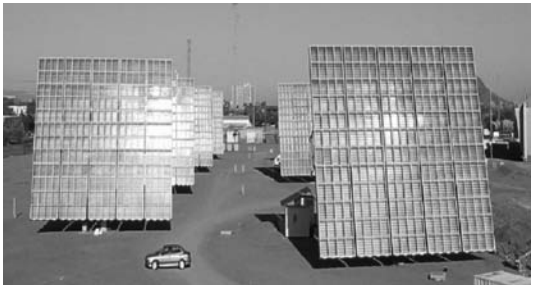

Fig. 12.20. The APS west field

the period from 2000 to 2003 and represent different versions and configurations of the maturing design. The 35-kW units, incorporating seven MegaModules each, are the latest design to be manufactured and installed at this site. The units in the west field have produced over 1185 MWh of grid energy since the start of operation.

12.9.2 APS STAR Center, East Field Site

A second field of Amonix units is located on the east side of the APS STAR facility (see Fig. 12.21). There are five 25-kW units, for a total of 125 kW, at this location. These units were installed during 2002 and have generated over 832 MWh of grid energy.

Fig. 12.21. East field at the APS STAR Facility

Fig. 12.22. The APS Glendale Airport site

12.9.3 Glendale Arizona APS Site

The Glendale Arizona APS site, installed in 2001, is located at the southwest corner of the Glendale airport (see Fig. 12.22). It consists of four 25-kW units, for a total of 100 kW. Since installation, this site has produced over 626 MWh of grid energy. There are no operation or maintenance personnel located at this site. The system's daily performance is remotely monitored from the APS STAR facility. If information from the monitoring system indicates a maintenance need, then personnel are deployed from the STAR facility.

12.9.4 Prescott Arizona APS Site

The APS is currently constructing a concentrating PV plant near Prescott, Arizona. There are currently five 35-kW units in operation at this site. The first 35-kW unit began operating in late 2002. Four additional 35-kW units were installed in 2003, for a present total of 140 kW. Figure 12.23 shows the five systems in operation. These five Amonix units have generated over 590 MWh of grid energy.

12.9.5 University of Nevada in Las Vegas Site

One Amonix 25-kW unit is installed at the Center for Energy Research at the University of Nevada at Las Vegas. This project is a joint effort by UNLV, Amonix and Arizona Public Service, under the direction of Mary Jane Hale of the National Renewable Energy Laboratory (NREL) and funded by the Nevada Southwest Energy Partnership.

This unit, shown in Fig. 12.24, is being operated by UNLV students to obtain performance and reliability data. Simultaneously, the students are learning about solar generating technology. This system started operating in late March 2004 and has generated over 105 MWh since that time.

Fig. 12.23. APS Prescott site

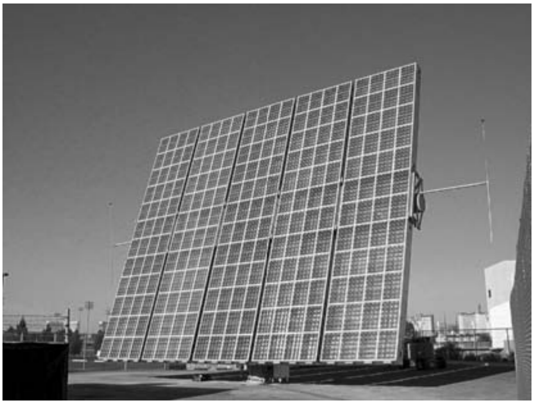

Fig. 12.24. Unit operating at the UNLV site

Fig. 12.25. Nevada Power site

12.9.6 Nevada Power Company Site in Las Vegas

Three 25-kW HCPV systems are operating at Nevada Power Corporation's Clark Generating Station, located in southeast Las Vegas. These MegaModules incorporate a new solar cell receiver plate design. This installation shown in Fig. 12.25 was completed in March 2006, and the system has generated approximately 40 MWh so far.

12.10 System Performance

Part of the Amonix development plan was to deploy multiple systems at different solar sites in order to test the hardware under various environmental conditions. Systems have been deployed in southern California, Nevada, Arizona, Texas and Georgia. Different lessons have been learned at each site. Some of the systems have been in field operation for 6 years. The accumulated grid energy generated, as shown in Fig. 12.26, is nearly 3.8 GWh.

A total of 132 MegaModules have been manufactured and installed in the field. These MegaModules incorporate a total of 6336 receiver plates and

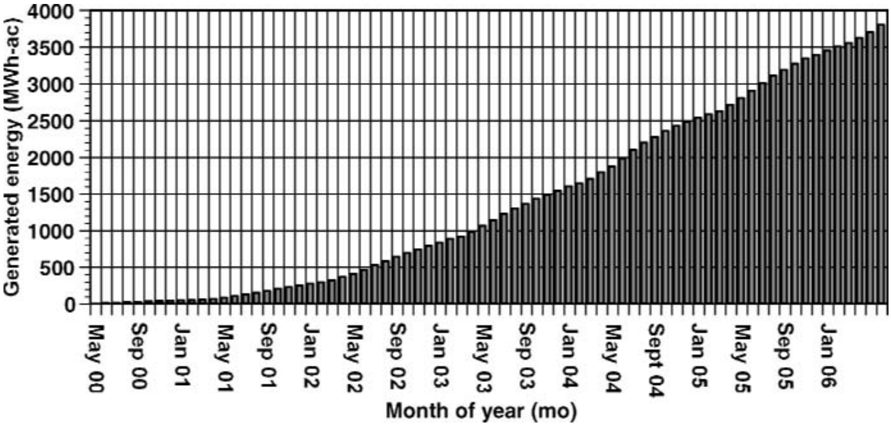

Fig. 12.26. Accumulated grid energy generated by the fifth-generation Amonix HCPV systems

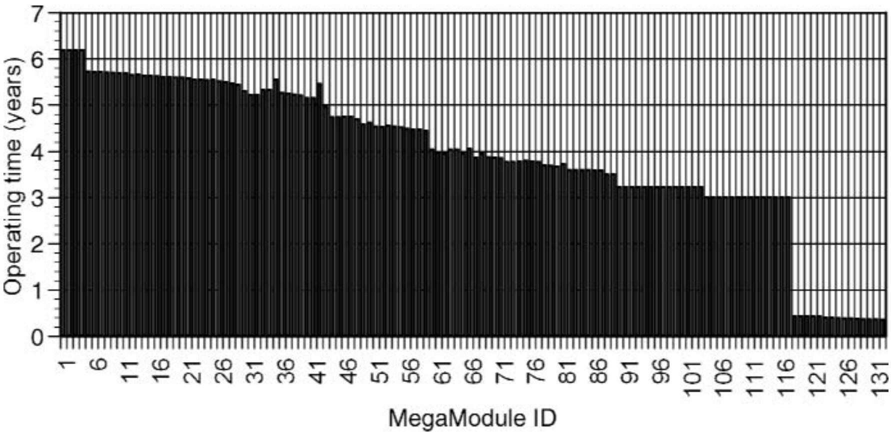

Fig. 12.27. MegaModule field operating time

152,054 solar cells. The total on-sun field operating time is over 510 years, as shown in Fig. 12.27. As lessons were learned from both manufacturing and field-testing, design changes were made to increase performance, increase system reliability and improve manufacturability of the system.

One of the main goals of the field-testing has been to assess long-term performance of the system. The electrical power production of each field unit has been recorded since its time of installation. One of the first units installed was the W3 unit at the APS STAR facility. The total net monthly generated electrical energy for the W3 unit is shown in Fig. 12.28. The performance was low in the first couple of months as issues were being resolved with the new design. The operation of this unit was paused in late 2004, and

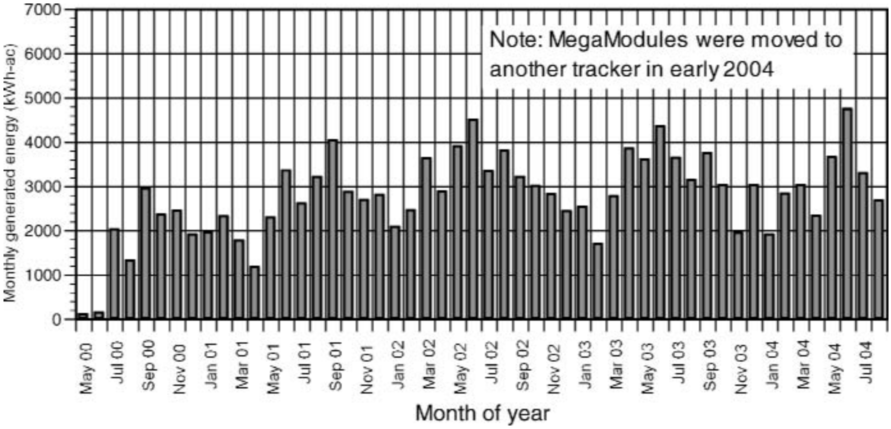

Fig. 12.28. Energy performance of HCPV system W3 at athe APS STAR facility

the unit's MegaModules were moved over to a new drive system that was under development at the time. Because of the seasonal monthly and year-to-year variation in the incident sun irradiance and other factors, such as dust-deposition on the lenses, temperature, wind, system-outage time, etc., it is difficult to determine from these data whether the performance changed over this time period, at least without further analysis.

A better estimate of the trend in the HCPV system performance can be obtained by dividing the (monthly generated energy) by the (total direct-incident sun irradiance energy for the month). Since it is desirable to be able to compare the performance trend of differently-sized arrays (25 and 35 kW, for instance), this mathematical ratio is also divided by the rated power level. The resulting number is referred to as the monthly performance energy factor (MPEF), as shown in Eq. (12.1):

$$MPEF = \frac{Monthly\ energy\ generated\ by\ the\ system}{(Total\ direct\text{-}incident\ sun\ irradiance\ energy) \times (Power\ rating\ of\ the\ system)} \qquad (12.1)$$

The MPEF for unit W3 is shown in Fig. 12.29. The MPEF values are not shown for the year 2000, because data on the local direct normal irradiance were not available for that time period. The chart's data stop in mid-2004, when unit W3's MegaModules were removed and then separately installed on different drives (these MegaModules are still in operation). Although the data presented in Fig. 12.29 do not indicate any general degradation, there is still significant variation in the data points. As discussed above, this variation is the result of ambient-temperature variation, wind-speed variation affecting wind-stow events, different rates of dust accumulation on the lenses, outage time, etc. The low MPEF values seen in May 2001 (month 5) and April 2004 (month 4) were the result of extended outages during those months.

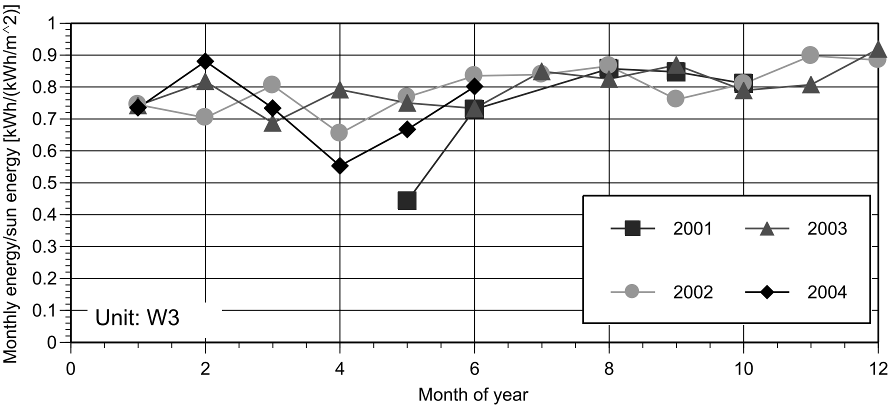

Fig. 12.29. Monthly energy performance factor MPEF of unit W3

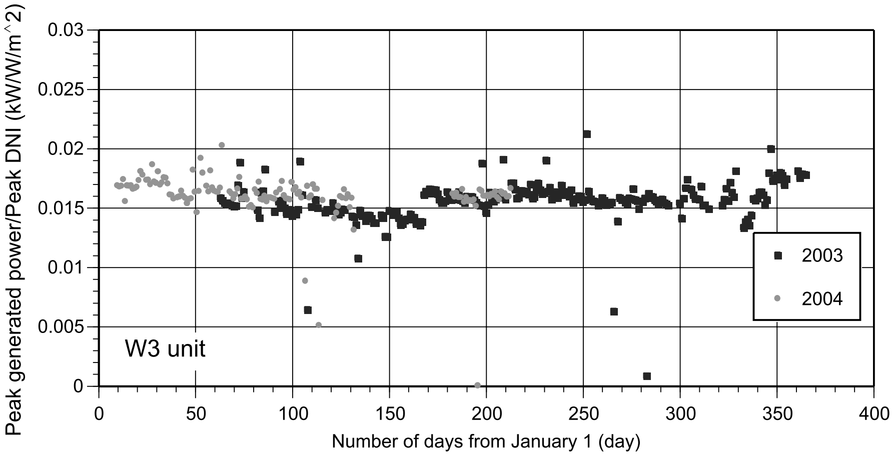

Fig. 12.30. Daily peak power normalized by the DNI

Amonix is also monitoring the peak-power performance of its installed systems. The peak power output divided by the DNI is shown in Fig. 12.30 for unit W3. Calculated values are not available before 2003, due to unavailability of DNI power data. Calculated values stop at year 2004, when unit W3's MegaModules were removed and installed on different drives.

12.11 Maintenance Operation

The Amonix HCPV system has not only been designed for high reliability, but also for low-field-maintenance requirements. Each MegaModule is itself modular, incorporating 48 removable solar cell plates, wired as two series-strings of 24 plates each. In the event of performance degradation or failure, each solar cell plate can be quickly tested by measuring its open-circuit voltage. Safe execution of this testing does not require that the system be shaded or moved completely away from the sun – the system need only be rotated approximately 10° from the sun, such that the focused sunbeams are no longer focused onto the solar cells. Once the malfunctioned solar cell plate is identified, it can be removed and replaced in situ, without disturbing any adjacent components. The malfunctioned solar cell plate can then be factory repaired, as its structure is also modular, incorporating replaceable solar cell assemblies.

The HCPV system uses a gearless hydraulic drive, and the majority of its components can be replaced without major disassembly of the system. The hydraulic actuators, valves, mechanical linkages and all of the bearings (except for the main azimuth rotational bearing) can be replaced without removing the MegaModule/torque tube structure. Only if there is a problem with the main drive structure would a crane be required for repair.

The control electronics, control valves, inverter, grid interface and transformer are modules that are all located at ground level for easy servicing. They are all separate modules that can be replaced with a minimum of interference with the other modules, minimizing the number of connection and disconnection operations.

Periodic maintenance tasks include washing the Fresnel lenses, greasing the drive bearings, and changing the hydraulic fluid and filter. Periodic washing of the lenses will help to maintain optimum system performance. The frequency of lens washing will depend upon the dustiness and rainfall frequency of the particular site. Greasing of the azimuth and elevation drive bearings should be done every 1–2 years. Amonix's field experience has shown that hydraulic fluid leaks are rare for its drive system, and are detected by the electronic control system. Fluid replacement has been required only every 1–2 years. The hydraulic fluid filter should be replaced once per year.

The UNLV HCPV system program includes the detailed recording of incidents and failures, and of operation and maintenance time spent on the system. The recorded O&M time for the UNLV system does not include the time for washing the lenses, nor does it include travel time (only on-site labour time is included). If the on-site O&M personnel had to call for assistance, only the time of the on-site personnel is included. A plot of the accumulated incident and failure labour time is shown in Fig. 12.31. The total incident and failure labour time per day is shown in Fig. 12.32.

12.12 System Cost

The current installed cost of the Amonix system at a production rate of 500 kW per year is in the $8/watt range. As the annual production rate increases, the estimated installed cost of the system will greatly decrease, as shown in Fig. 12.33.

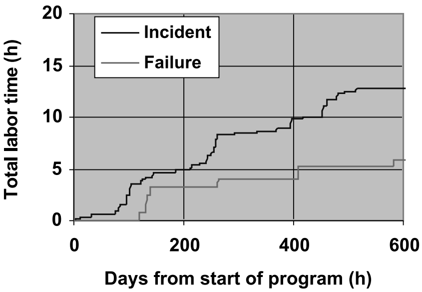

Fig. 12.31. Incident and failure time

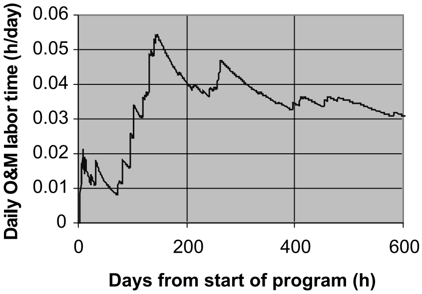

Fig. 12.32. The O&M per day

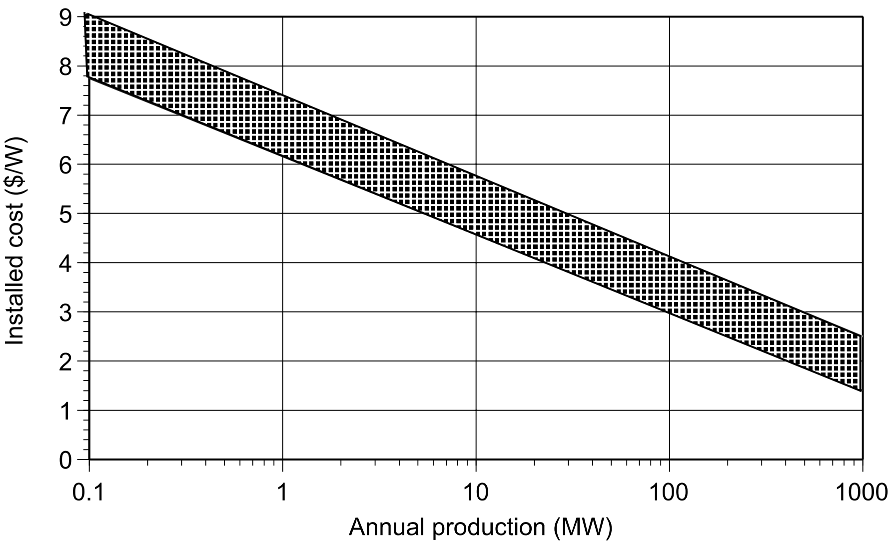

Fig. 12.33. Estimated cost of the installed system

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